A framework for laparoscopic simulations

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Abstract

Due to their numerous advantages, laparoscopic surgical procedures are increasingly becoming common in the operation theatres over the past few decades. Virtual reality training simulators have played a significant role during this transition from traditional to laparoscopic procedures by enhancing surgical skills, such as hand-eye coordination in laparoscopy, and practising surgical scenarios that cannot be easily created using physical models. This paper presents a general framework for such a training simulator while identifying its key components and their specific roles in enhancing various laparoscopic skills. The paper also describes a laparoscopic simulator, developed in our lab, based on the proposed framework. The results are promising and open new doors for research and development.

Keywords: Laparoscopy, Robotic surgery, Surgical simulations.

Introduction

For sophisticated training, ranging from a fighter jet flight to project management, virtual reality (VR) simulators play an important role for the learning of the trainee. Laparoscopy, which is a type of minimally invasive surgery (MIS) that allows inserting an endoscope and other instruments into the patient's body through small holes and operating upon the patient using the on-screen output from the endoscope, is no exception. VR simulators greatly facilitate a laparoscopic surgeon's hand-eye coordination, depth perception, ability to work within a confined space and the ability to control non-intuitive pivoted motion of instruments. Similarly, with the introduction of the surgical robots, such as ZEUS[1] and Da-Vinci,[2] it became more important to train the surgeons to properly use such robots. Due to the high cost of commercially available surgical robots, VR simulators provide a more economically viable option to provide robotic surgery training. Moreover, a surgical simulator is a safer option than practising on live patients and they provide a better training because tissue properties of body are more lifelike in simulators than in cadavers.

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There are number of commercial surgical simulators, including RoSS[3] and Voxel-Man tempo,[4] that are deployed in surgical training institutes. RoSS is simulator for the Da Vinci surgical system with a master console that closely resembles the Da Vinci console. In contrast, Voxel-Man tempo is based on the off-the-shelf PHANTOM OMNI® joysticks for controlling the virtual surgical instruments. Similarly, various simulators for learning the conventional laparoscopic surgery are also commercially available. Some commonly used ones include LapSim[5] and LapMentor.[6] However, these commercially available simulators are quite expensive. According to P. Brennen et al.,[7] surgical simulators are the most widely used simulators, yet they claim that "Surgical training is undermined by inadequate provision of laparoscopic surgical simulators". As per our analysis, this is mainly due to the high cost of the laparoscopic simulators. Thus, the problem can be resolved if a state-of-the-art surgical simulator is available at a lower cost. The availability of such a simulator would greatly facilitate the introduction of laparoscopic surgeries in developing countries and thus allow them to reduce their healthcare burden. There is a plethora of laparoscopic simulators available that are inexpensive but do not provide up to the mark training. For example, one can even find YouTube® videos on making one's own laparoscopic simulator at home.[8,9] The main contribution of this paper is to provide a concise framework of a laparoscopic simulator that is based on solid scientific principles and captures most of the training requirements of a laparoscopic surgeon. The proposed framework can be used as a yardstick to measure the effectiveness of a cost-effective laparoscopic simulator and thus judge if it can fulfil the required training needs.

Proposed Framework

A laparoscopic simulator is primarily made up of three main modules: Mechanical interface, Controller circuit and Software application (Figure-1).

The mechanical interface allows the user to interact with the software application of the simulator. In the case of conventional laparoscopic training simulators, such as LapSim and LapMentor, the mechanical interface is designed to mimic the actual laparoscopic tool in structure and functionality. For a robotic laparoscopic

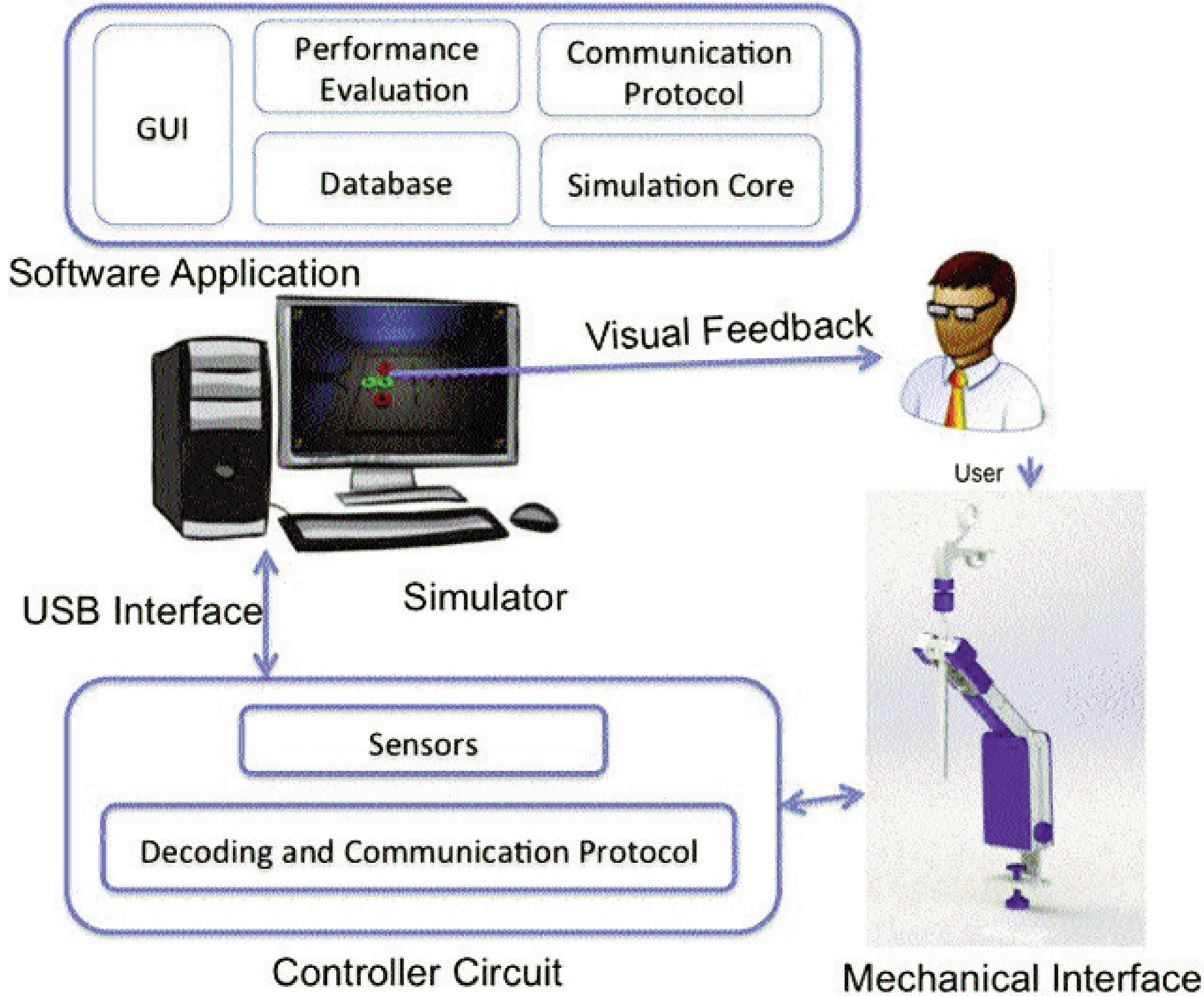

Figure-1: Proposed Framework for a Laparoscopic Simulator.

trainer, the mechanical interface should mimic the manipulators of the actual surgical robot, such as SOPHIE,[10] RAVEN,[11] and DLR MIRO,[12] so that the users can get the same feeling as a real surgery during the training process.

The controller circuit is usually invisible and is composed of sophisticated electrical components that are responsible for the interaction and communication between the mechanical interface and the software application. Primarily, the controller circuit is composed of smart sensors, which are placed on the joints of the mechanical interface to gauge the mechanical movements. These movements are then transferred to the computer for manipulating the software application.

The software application receives the data corresponding to the mechanical movements and translates it into motions of the simulated instrument. Besides, it also presents the user with a graphical user interface (GUI) to interact with. This GUI includes various options like selecting exercises, using web resources and viewing past performance. A local database runs at the backend to maintain users' records. However, the main function of this module is to run real-time simulations for training the users. The philosophy is to introduce more rigorous exercises that improve and assess both the motor and cognitive skills of a surgeon. For the improved motor skills, simulation exercises should consist of more dexterity demanding exercises than presented in real life scenarios. Similarly, for the improvement of surgeon's cognitive skills, including real-time decision-making, unexpected and rare scenarios should also be presented. Such unexpected scenarios can be constructed by using machine-learning algorithms and by combining the well-known set of problems in intelligent fashion. In simulation, the unusual or rarely reported cases can also be introduced.[13] For laparoscopic training, it is very important to have the objective and adaptive feedback that helps and record the progression of the trainee.

Development of a platform and exercises

Inspired by the above-mentioned framework, we developed a new high-fidelity virtual reality laparoscopy trainer: SmartSIM[14] (Figure-2), in the labs of National University of Sciences and Technology (NUST), Pakistan.

Instead of using the commercially available joysticks for the surgeon console, we used custom-made manipulators to provide close to reality experience to the learners. The mechanical interface of SmartSIM is a mechanical manipulator that is designed to mimic the traditional laparoscopic tool in structure and functionality. A laparoscopic instrument is usually a 5-Degrees of Freedom (DoF) mechanical structure. The point of entry into the body inhibits the free movement of the instrument and acts as a pivot around which the tip of the instrument moves. This leaves the surgeon with five possible movements: pitch, yaw, roll, depth and open/close of gripper. These identified motions along with the workspace requirements formed the basis for designing the Mechanical Interface for SmartSIM.

The SmartSIM system uses encoders, installed on the joints of the Mechanical Interface, to gauge the mechanical movements. These movements are then recorded by a microcontroller and transferred to the computer via a full duplex communication protocol using the Universal Serial Bus (USB) interface. These features are handled by the Controller Circuit module of the system.

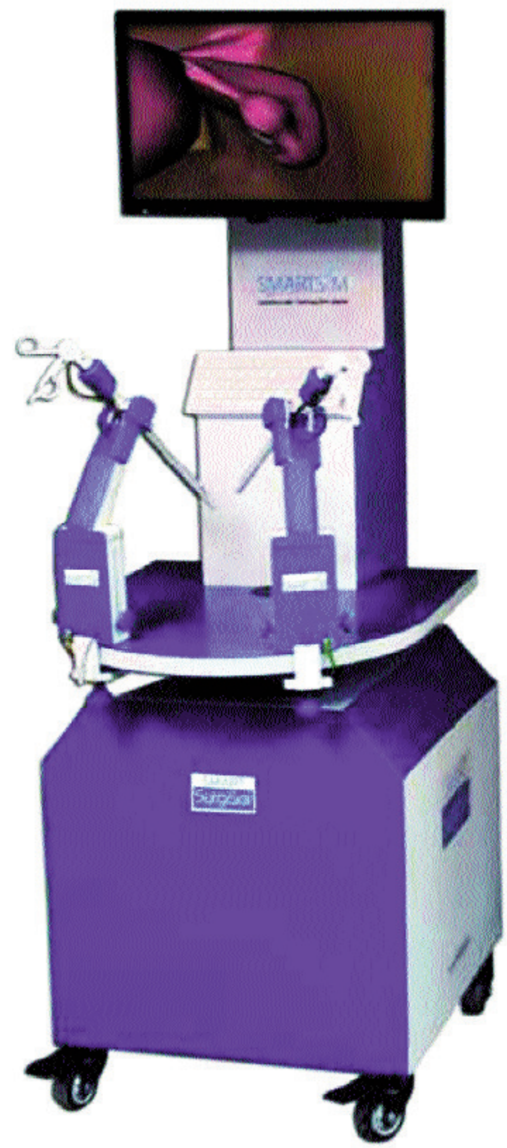

Figure-2: SmartSIM Laparoscopic Simulator.

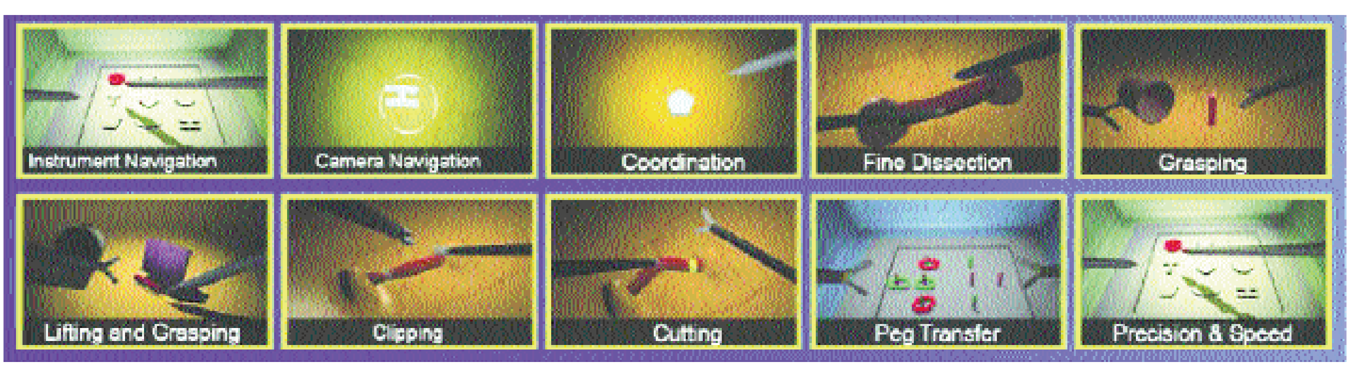

Figure-3: Top 10 basic skills for laparoscopic surgery are included in SmartSIM.

Figure-4: General Surgery Exercises in SmartSIM.

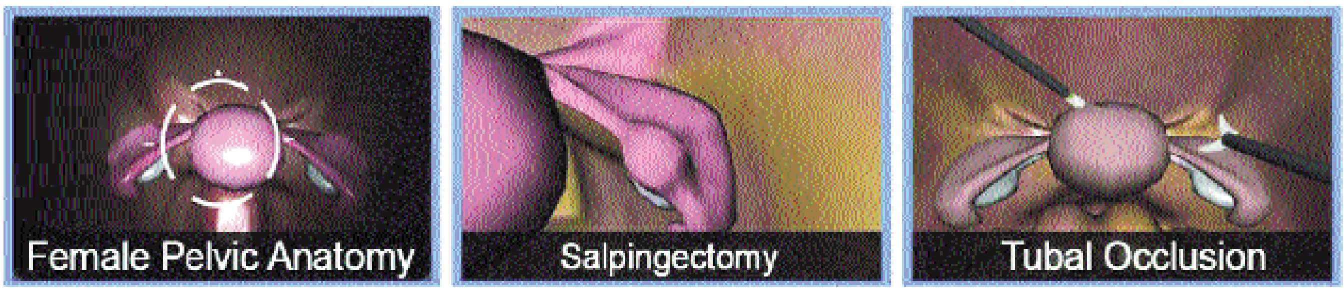

Figure-5: Gynecology procedures in SmartSIM.

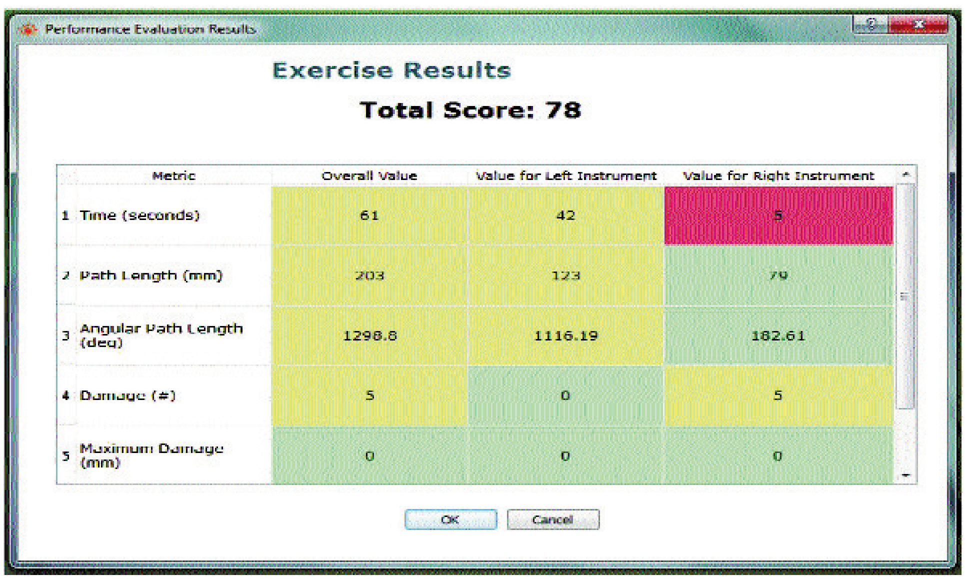

Figure-6: Evaluation metrics in SmartSIM.

The simulator software of SmartSIM works on the widely-used Windows operating system. The training exercises of the software application of SmartSIM have been developed using the generic physics engine simulation open framework architecture (SOFA). SmartSIM offers about 10 basic exercises (Figure-3) to enhance the motor skills of the trainee and seven advanced exercises depicting various scenarios encountered during general surgery (Figure-4) and gynaecology procedures (Figure-5). Furthermore, we have also introduced a new type of intelligent metrics in SmartSIM that successfully implements the idea of independent learning via simulators without the need of supervision from expert surgeons. During each exercise, the skills of a trainee are assessed and the results are displayed at the end of each exercise. The red regions depict the problem areas and the system proposes the remedies to overcome these deficiencies by providing adaptive exercises to improve the skills in the weak area (Figure-6).

Discussion

The main purpose of a laparoscopic simulator is to train surgeons and thus it is very important to explicitly mention the learning outcomes of each exercise in a simulator. Moreover, the objectives of every exercise module should be very clearly mentioned as well to provide instructions for accomplishing the goals in an optimised way. Simulation videos recorded from the exercises of expert surgeons can be very helpful for a

Table: Comparison of the different laparoscopic simulator.

Feature	Description	Smart SIM	Pro MIS	Lap Sim
Modules and Tasks of the Simulator	Basic Skills:			
	Navigation / Coordination	Y	Y	Y
	Touching	Y	N	Y
	Grasping	Y	Y	Y
	Stretching / Traction	Y	Y	Y
	Translocation	Y	Y	Y
	Advanced Skills:			
	Clip Application	Y	Y	Y
	Transaction / Cutting	Y	N	Y
	Dissection	Y	Y	Y
	Diathermia	Y	Y	Y
	Suturing	Y	N	Y
	Knot Tying	Y	Y	Y
Recorded Parameters	Time	Y	Y	Y
	Path Length	Y	Y	Y
	Smoothness	N	Y	N
	Errors	Y	N	Y
Feedback	Progression curve of recorded parameters	Y	Y	Y
	Real playback of the task	Y	Y	Y
	Virtual playback of the task	N	Y	N
Need for Observer	Is an expert observer needed for evaluation of the performance of the task?	N	N	N
	An "expert" observer is only needed for the feedback / help with problems	Y	Y	Y
	Trainee can train and evaluate modules without an "expert" observer	Y	Y	Y
Instructions	Written instructions of tasks on the screen	Y	N	Y
	Demonstration video	Y	Y	Y
	Spoken instructions during the task	N	N	N
	Guidelines on the screen during the task	Y	N	Y
Validation	Is the simulator completely validated?	Y	Y	Y

trainee. Similarly, videos from real surgeries can play a vital role in enhancing the cognitive skills and allow the trainee to relate the simulation-based exercise to its real-life application. We have tried to include the above-mentioned features in our simulator and a comparison of SmartSIM with the mainstream commercially available laparoscopic simulators ProMIS and LapSim is presented, with Y/N denoting Yes/No (Table).

Conclusion

This paper provides some general guiding principles for the construction of a state-of-the-art laparoscopic simulator. The three main components of such simulators include a mechanical interface, controller circuit and the software application. Out of these three, the software application is the most important component and besides the regular training exercises, it should provide some efficient ways of providing feedback to the trainees. To illustrate the practical effectiveness of our proposed ideas, we have developed SmartSim simulator that is not only cost-effective but is also at par with other commercially available simulators.

Disclaimer: None.

Conflict of Interest: None.

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